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FILE

MEMORANDUM FOR PRS (In-House/Contractor Publication)

FROM: PROI (STINFO) 29 August 2002

SUBJECT: Authorization for Release of Technical Information, Control Number: **AFRL-PR-ED-VG-2002-209**

55449

Tom Hawkins (PRSP), "Green Propulsion – A USAF Perspective" (viewgraphs)

5th Int'l Hydrogen Peroxide Propulsion Conference **(Statement A)**
(Lafayette, IN, 15-19 September 2002) **Deadline: 12 Jun 01 = Past due)**

GREEN PROPULSION- A USAF OVERVIEW

September 2002

Dr. Tom Hawkins

Air Force Research Laboratory

Distribution authorized for public release

Issues and Drivers

- Increased Testing and Operations Costs:
  - System Handling/Fueling
  - Monitoring System in Field
  - Delays in Launch for Corridor
    - Hazardous/Carcinogenic Vapor (Respiratory Route)
    - Dermal Toxicity

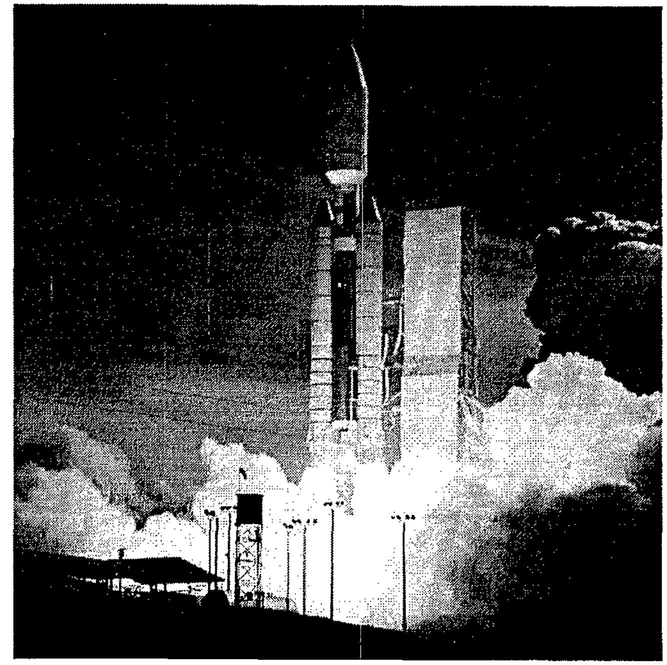
- Performance of SOTA Propellant
  - Desire Improved Isp and D*Isp
    - Improved Capabilities (Payload and Range)

System Handling/Fueling

Propulsion Systems

- Solid Boost Propulsion
  - Perchlorate-Based Propellants

System	Mission
Titan IV	Satellite/Payload Delivery

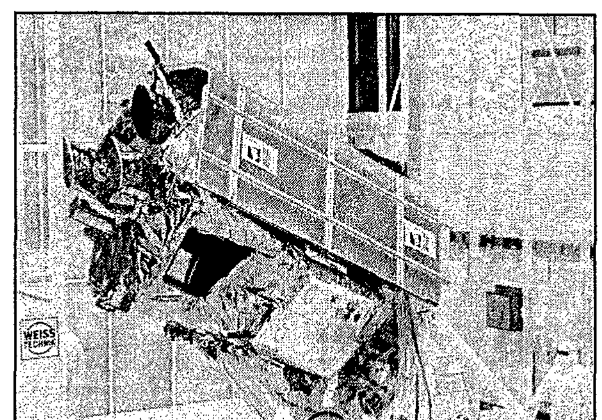


- Liquid Propulsion
  - NTO/MMH Bipropellant

System	Mission
Delta IV	Satellite/Payload Delivery

- Spacecraft Propulsion and EPU Power
  - NTO/MMH Bipropellant
  - Hydrazine Monopropellant

System	Mission
FltSatCom	Communications



AFRL "Green" Propellant Development

Background

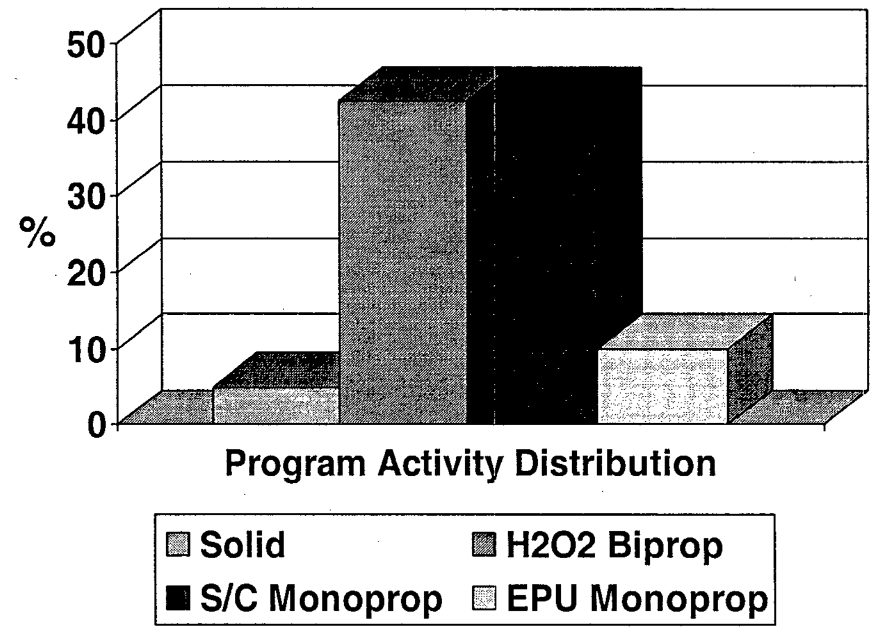
- Performing "Clean" Solid Propellant R&D Since the mid 1980s
- Led Programs in Developing "Clean" Propellants and Manufacturing Processes
- 1997 White House Closing-the-Circle Award for Innovative Environmental Technology Development
- Developing Energetic, 'Green' Liquid Oxidizers Since 1993
- Initiated work in 'Green' Monopropellants in 1995

USAF Green Propellant Efforts

Over Last Year:

- USAF Liquid Propulsion
  - Evaluating Peroxide-Based Bipropulsion
  - Developing Green Spacecraft Monopropellant
  - Developing Alternative Monopropellant for APUs

- USAF Solid Propulsion
  - Completed SERDP Program Developing Greener Propellant



SERDP Green Missile Propellant

Objective

- Try to Achieve Performance Levels of Commercial Space Launch, Solid Propellant
- Determine the Potential of Nanofuels to Improve Properties (Performance, Mechanical Properties, Hazards, etc.) of Cleaner Combusting Solid Propellant for Space Launch Boosters

WFZ Baseline Propellant:

Developed as a Chloride-Free, Space Launch Booster Propellant Under USAF Contract by Alliant Technologies and Demonstrated in 800 lb. Motor

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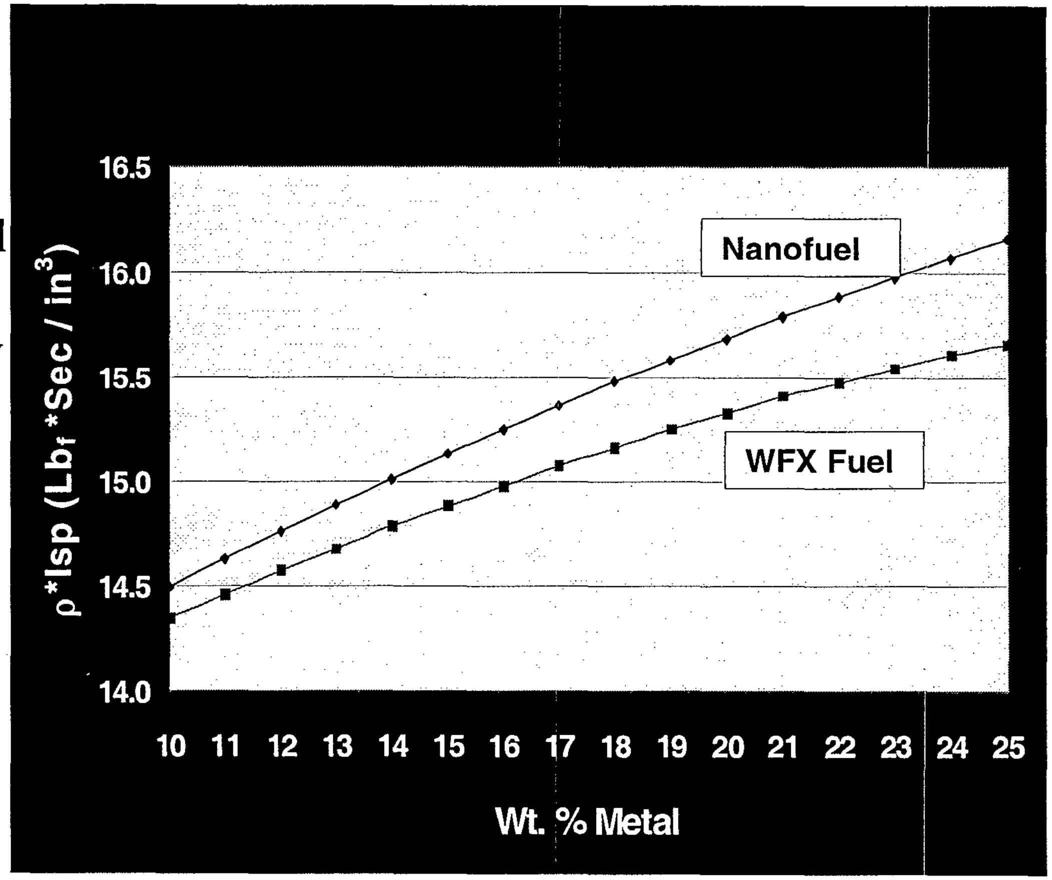
Payoff

Need: Improvement Over WFZ in Density Impulse

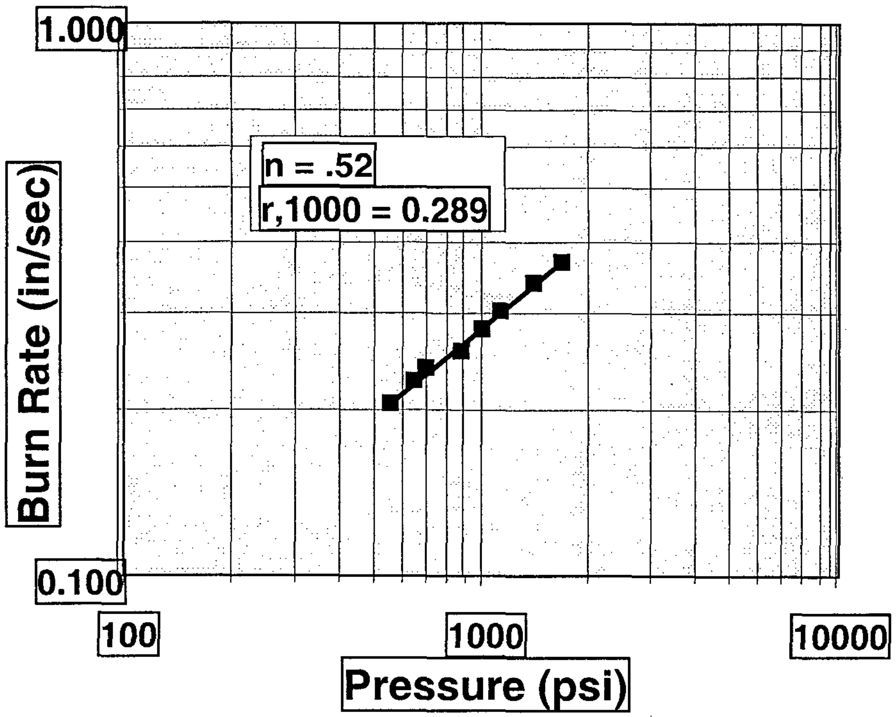
- **Effect of Nanofuel on Propellant Isp**
  - **Little Change in Theoretical Isp in Substituting WFX Fuel with Nanofuel**
- **Effect of Nanofuel on Propellant Density**
  - **Significant Increase in Propellant Density and Volumetric Impulse with Nanofuel**



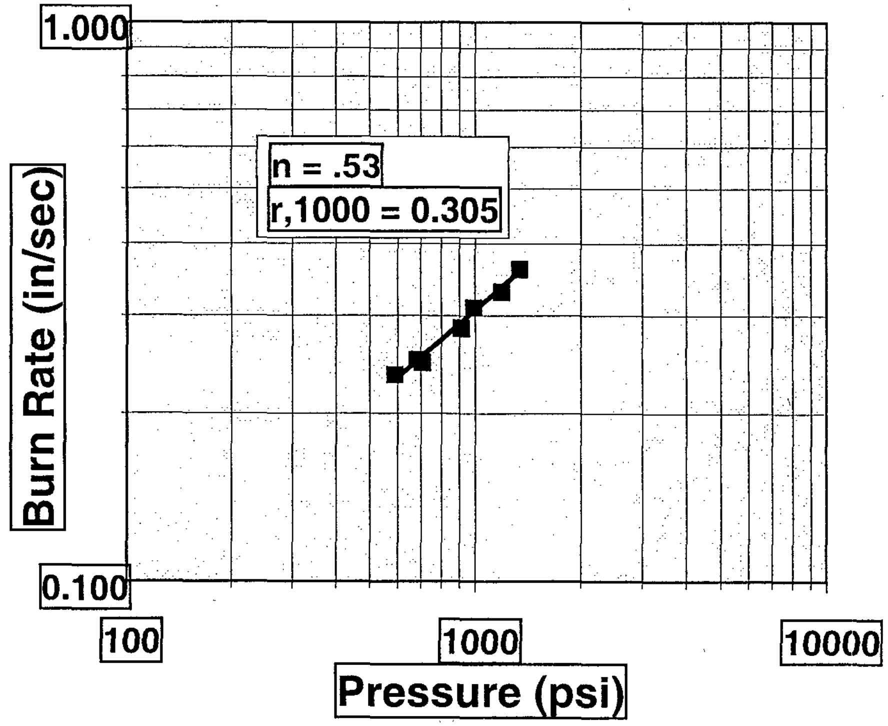
Motor Ballistics

Successful Series of Small Motor Firings Using Modified Propellant

WFZ Baseline



Modified Propellant-18% Nanofuel

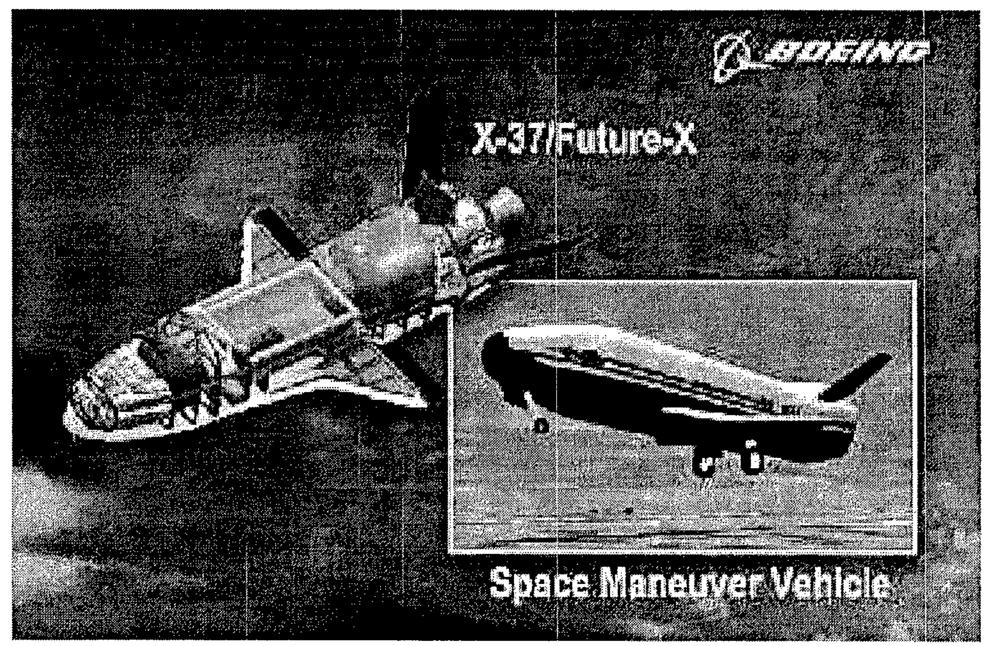


Program Summary

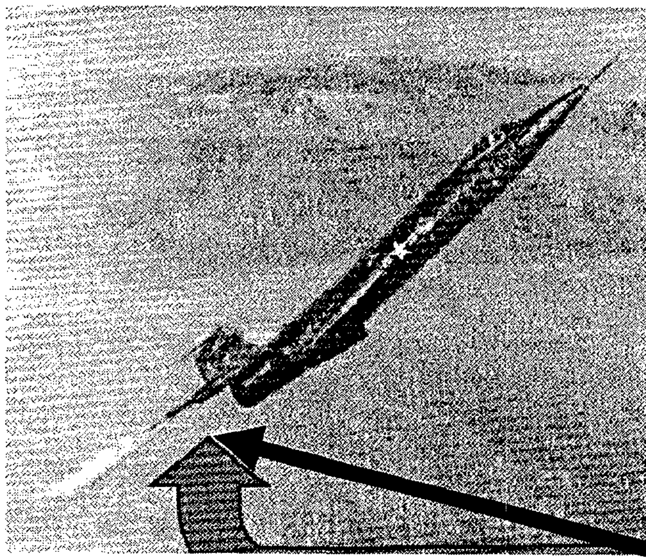
- Nanofuel Addition Did Not Adversely Affect Propellant Processability (End-Of-Mix Viscosity Remained <3KP)
- Hazards
  - Modified Propellant Maintained “Zero” Card (NOL Card-Gap Test)
  - Increased Propellant Impact Sensitivity (160 Kg*cm) and Friction Sensitivity (265 N), But Still Within an Acceptable Range
- Significant Increase in ρ*Isp from 15.5 to 16 lbf*sec/in^3 with Little Change in Isp
  - Equates to > 500 lb Increase in Payload (GSO) Compared to Motor with WFZ Clean Propellant
- SERDP Program Completed- USAF Continuing Research in Nanofuels

Peroxide-Based Bipropellant

- Boeing X-37 technology carried on Air Force Long Range Plan as SMV vehicle technology demonstrator
- Proposed X-37 main engine, AR2-3, meets reusability objectives, but did not meet current storable bipropellant performance objectives
  - AR2-3 Isp 246s vs. 320s
  - AR2-3 developed 1950's
- Technology short fall prompted Congress to fund AFRL SMV Tech Demo



H202 Reusable State-of-the-Art



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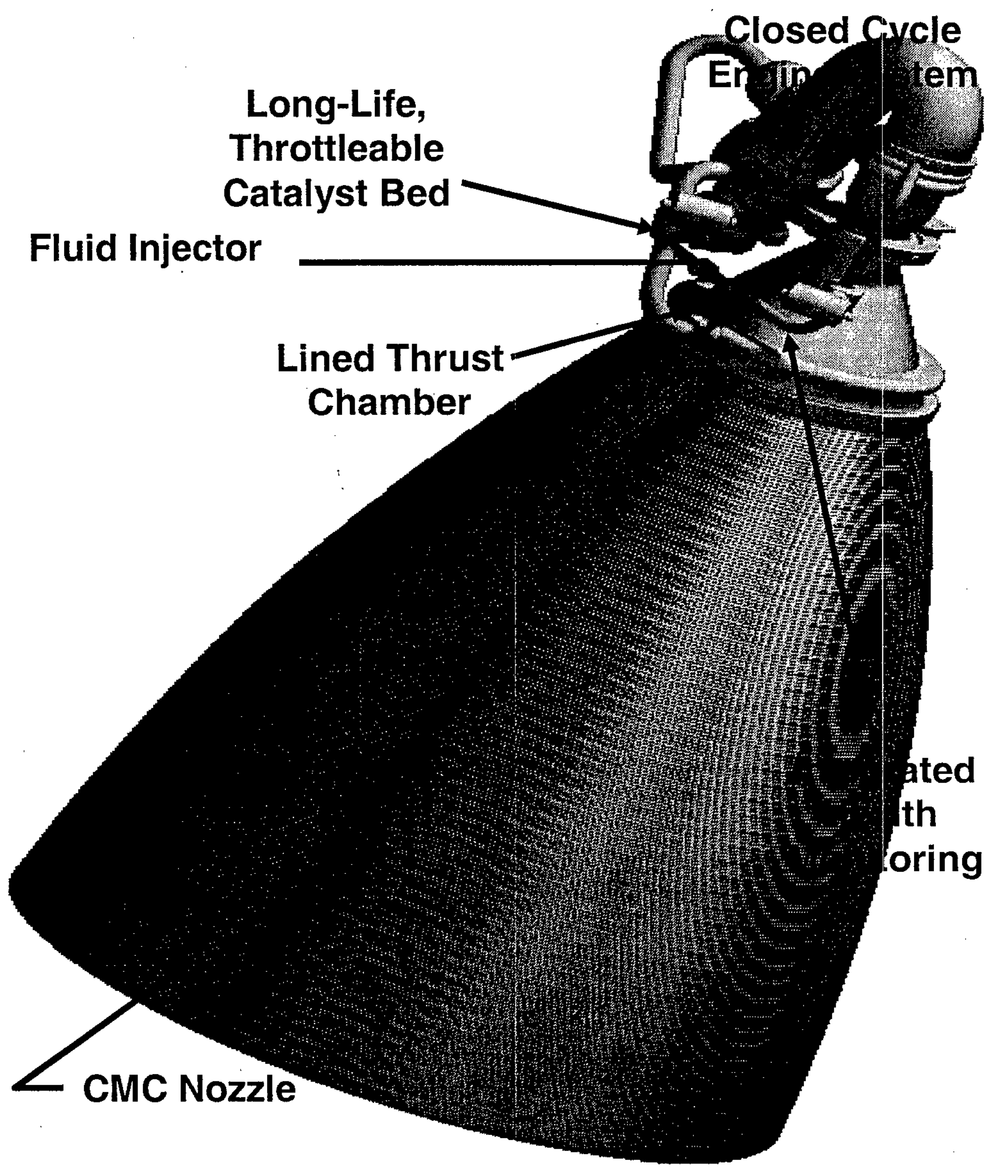
AR2-3

Phase II Aerojet Engine Technology

- Aerojet's Advanced Reusable Rocket Engine (ARRE) Provides the Air Force with an Advancement in Reusable, Rocket Engine Technology for SMV Applications
  - 98% Hydrogen Peroxide Propellant Improves Vehicle Operations
  - Closed-Cycle Engine System Provides High Performance and Throttleability
  - Component Designs That Improve the Engines Life and Enable its Reusability and Operability



Program Status

- System preliminary design review complete
- Thrust chamber (injector & chamber) fabrication/assembly underway
- Injector test scheduled for 1QFY03
- Injector test with regeneratively cooled chamber scheduled for 2QFY03

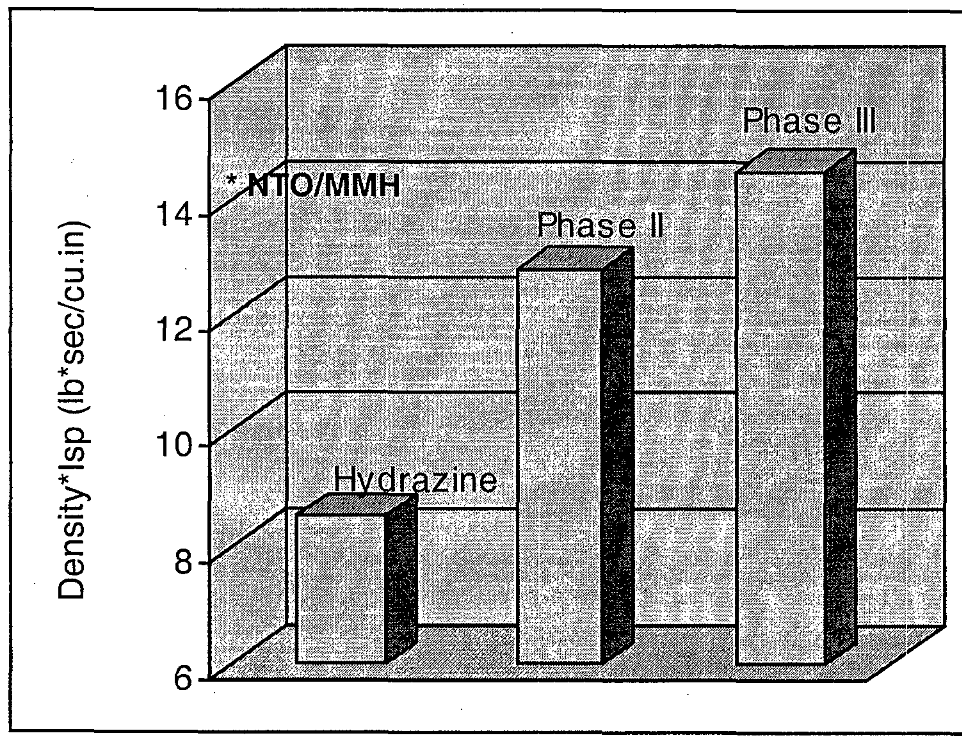
Advanced Spacecraft Monopropellant Performance Objectives

- Increase Density Isp of New Monopropellants for IHPRPT Demonstration:

  50% by 2005

  >70% by 2010

- New Monopropellants to Have Reduced Toxicity- Allowing Operations w/o SCAPE-suited Crews



USAF is Lead for IHPRPT Monopropellant Development

Desirable Monopropellant Properties

Characteristic	Objective
Density Isp [2.07 MPa- vac, exp=50]	>50 % (Over SOTA)
Vapor Toxicity	Does NoT Require SCBA
Carbon Content	No Solid Carbon Forms in Theoretical Exhaust
Melting Point	< 2°C
Detonability [NOL Card Gap]	Class 1.3; (Prefer 24 Cards Maximum (E_{50}))
Impact Sensitivity [Drop Weight]	20 kg-cm Minimum (E_{50})
Adiabatic Compression [U-Tube Test]	No Explosive Decomposition (Pressure Ratio of 35)
Thermal Stability	< 2% by wt. Decomposition for 48 hrs at 75 °C
Critical Diameter	No Propagation in Lines of < 1.91 cm Diameter

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Advanced Propellant Characteristics

Properties	AFN1	Hydrazine
Isp , sec; (a)	261	233
Density , g/cc	1.46	1.01
Chamber Temp. (Theoretical) , K	2083	883
Carbon Content of Exhaust; (b)	none	none
Impact Sensitivity*, kg-cm (5 negatives)	60	>200
Friction Sensitivity, N (5 negatives)	300	>371
NOL Card Gap (at 69 Cards)	negative	negative
Thermal Stability, %wt loss/48hr,75°C	1.96	(< 0.1)
Melt Point, C	<-22	1

a: Theoretical, calculated with 2.07 MPa chamber pressure, exhaust to vacuum, 50/1 expansion
b: as soot or solid carbon (by theoretical computation)
c: by DSC; melt transition was broad, melt peak reported
*: For reference, n-propylnitrate had an impact sensitivity of 8 kg-cm

Propellant Displays Acceptable Safety/Sensitivity Properties For Continued Development

Toxicology

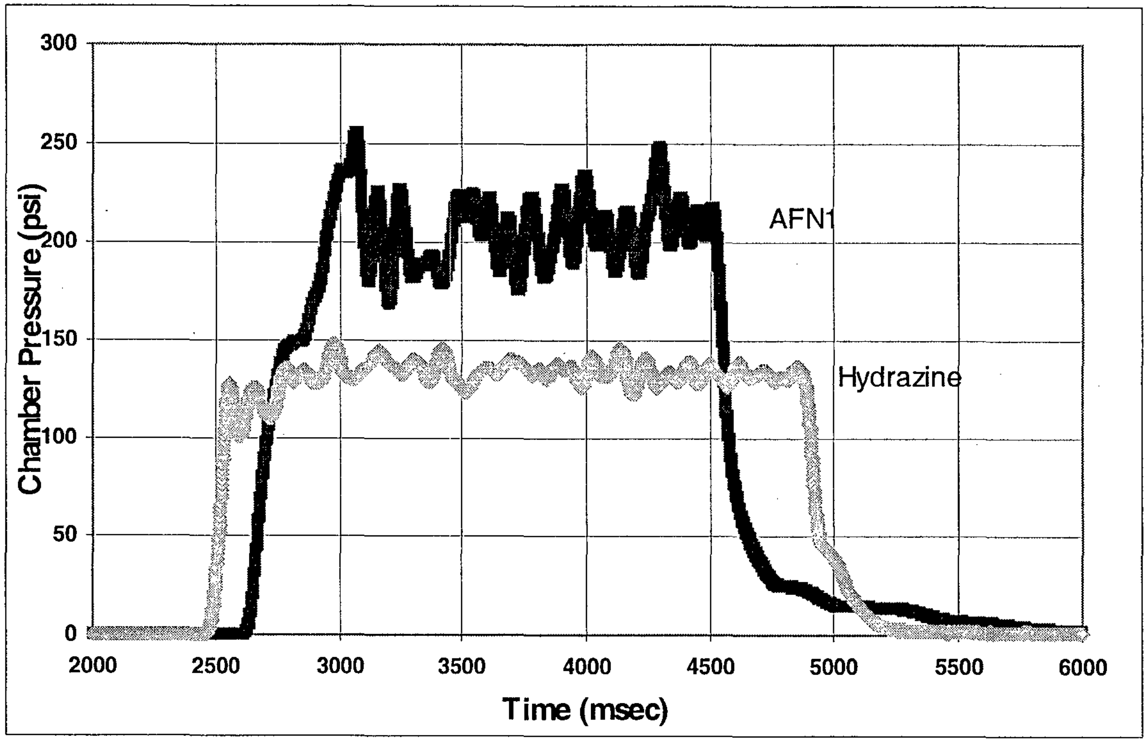
Results

PROPERTY	AFN1	HYDRAZINE
LD50 (rat), mg/kg	325-367	60
Dermal Irritation	Slight-Moderate	Corrosive
Genotoxicity (Ames)	3 Negative/ 2 Positive	Positive

Evaluation:

- **6X Less Oral Toxicity Than Hydrazine**
- **Low Dermal Irritation**
- **Genotoxicity (Bacterial) in 2 of 5 Strains (and negligible vapor hazard)**

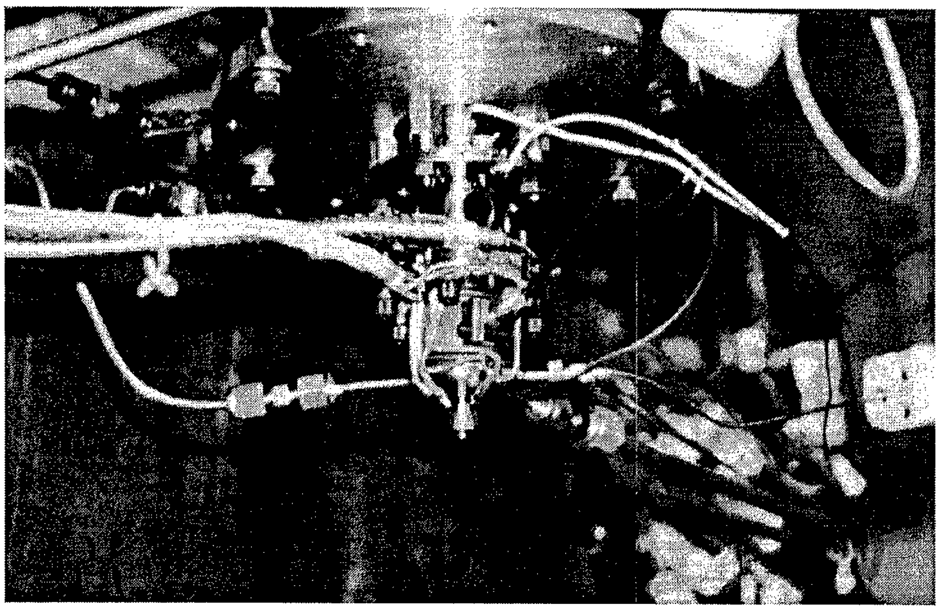
High Performance , Reduced Toxicity Monopropellants



- Thruster Chamber Pressure Profile for High Performance Propellants
- Ignition Delay Varied (ca. 150 msec Rise Time)
- Stable Combustion (± 5 - 15% Variation in Pressure)

High Performance, Reduced Toxicity Monopropellants

- Multi-kg scale-up of AFN1 propellant
- Testing underway with industry partners

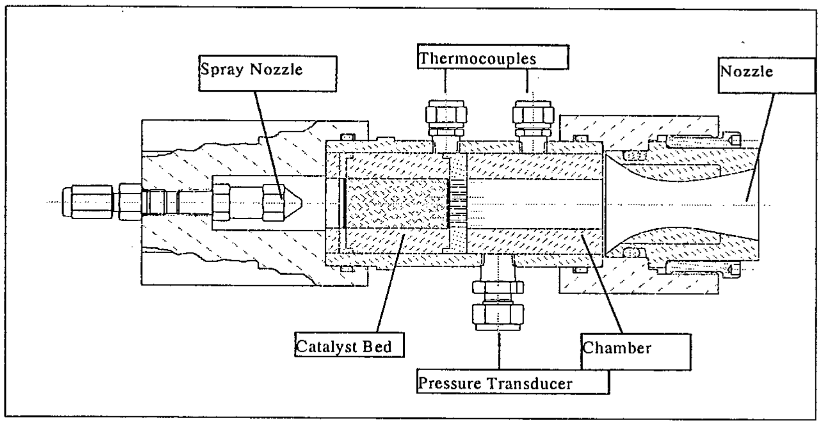


Initial Results-Thruster Test

- Repeatable Ignition
- Catalyst Degradation
- Acceptable Pc Roughness

Demonstration Program

- Thruster demonstration program initiated 2002
- AFRL supplies propellant expertise, materials and characterization to commercial hardware integrator



- Incorporate high temperature hardware
- Maximize heat dissipation

- Objectives:
  - Engineer feed and injector system
  - Design efficient catalyst bed configuration
  - Optimize propellant for fast ignition

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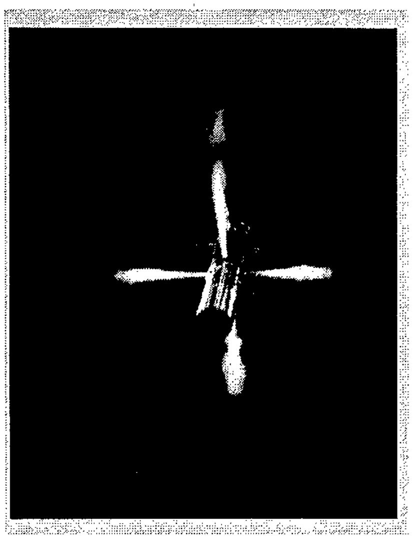
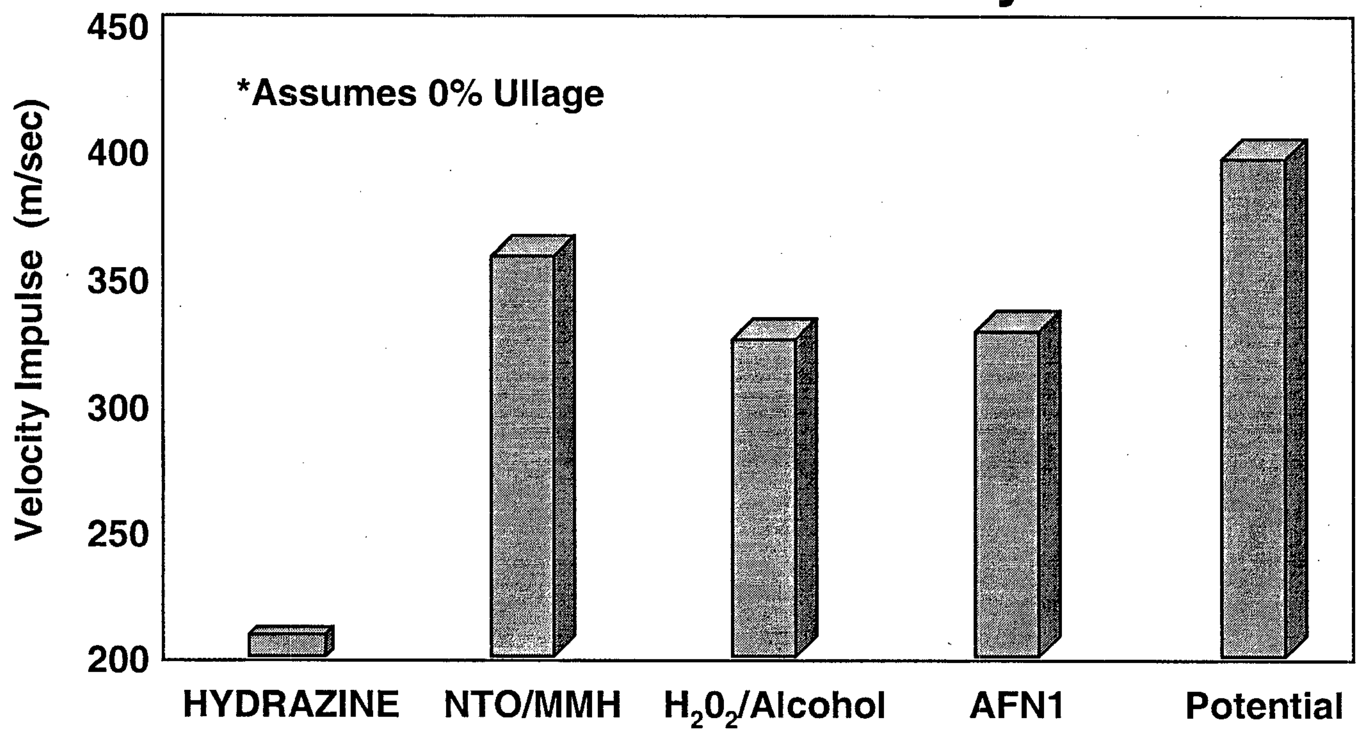
Performance Payoff



Microsatellite Trade Study



Monopropellant Performance Range

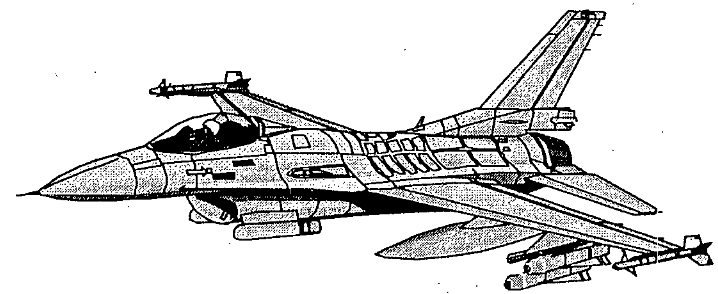
Monopropellant Performance Can Exceed:

- Hydrazine
- H_2O_2/Alcohol
- NTO/MMH

High Performance Monopropellants -Summary-

- Continue monopropellant development & characterization
  - Promising, new approaches
    - Incorporating high energy density molecules
    - Encouraging propellant properties
    - Performance potential to meet/exceed bipropellant
      - Simpler, lighter propulsion system
  - Critical work remains
    - Stability, material compatibility, rheology
    - Propellant ignition , high temperature catalyst/materials
      - Teamed with industry to transition research product

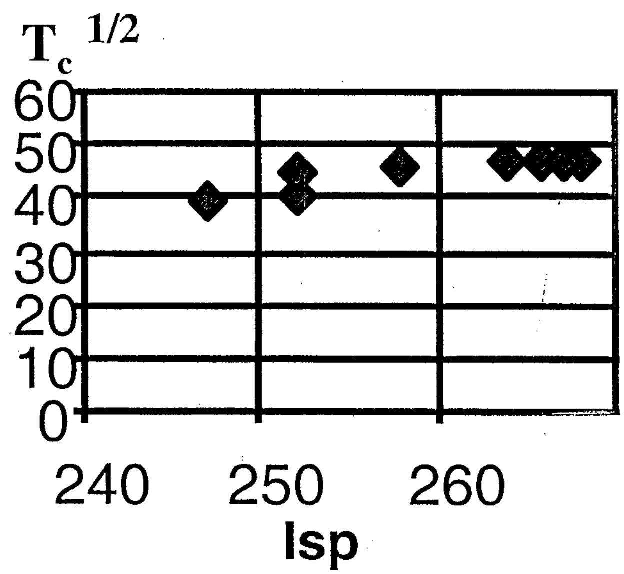
Hydrazine Replacement for Auxiliary Power Units



Can Spacecraft Monopropellant Approaches be Modified for APUs?

I. Reformulate Propellants

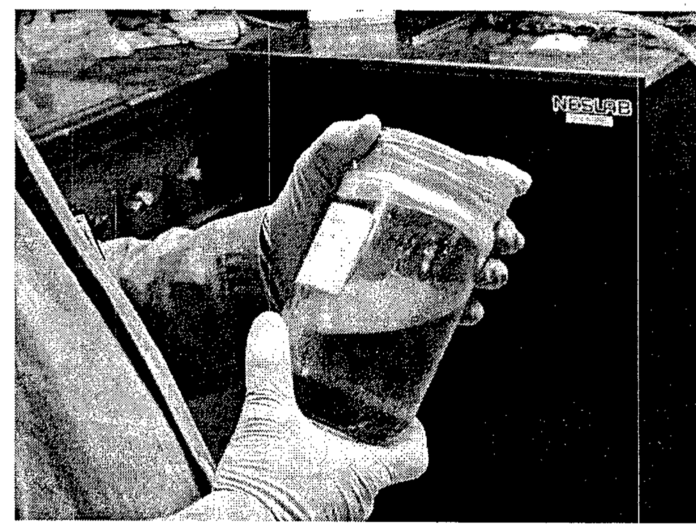
- Lower Performance/Combustion Temperature (Compatible with Shell 405 Catalyst)



APU Feasibility Assessment Objectives

II. Property Characterization

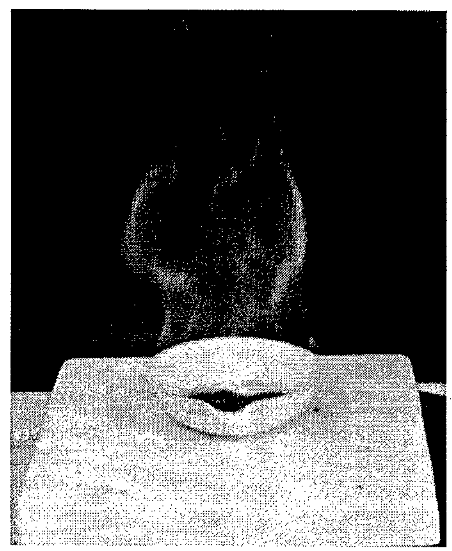
- Select Propellant Types
- Produce Candidates for Evaluation
- Assess Physical, Safety/Hazard Sensitivities
  - Liquidity (233 K)
  - Detonability
  - Impact/Friction
  - Adiabatic Compressibility
  - Toxicity (Qualitative)



APU Feasibility Assessment -Objectives-

II. Property Characterization (cont.)

- Evaluate Ignition Delay of Candidates on Shell 405
  - Drop/Splash Plate Test
  - AFRL Pino Test

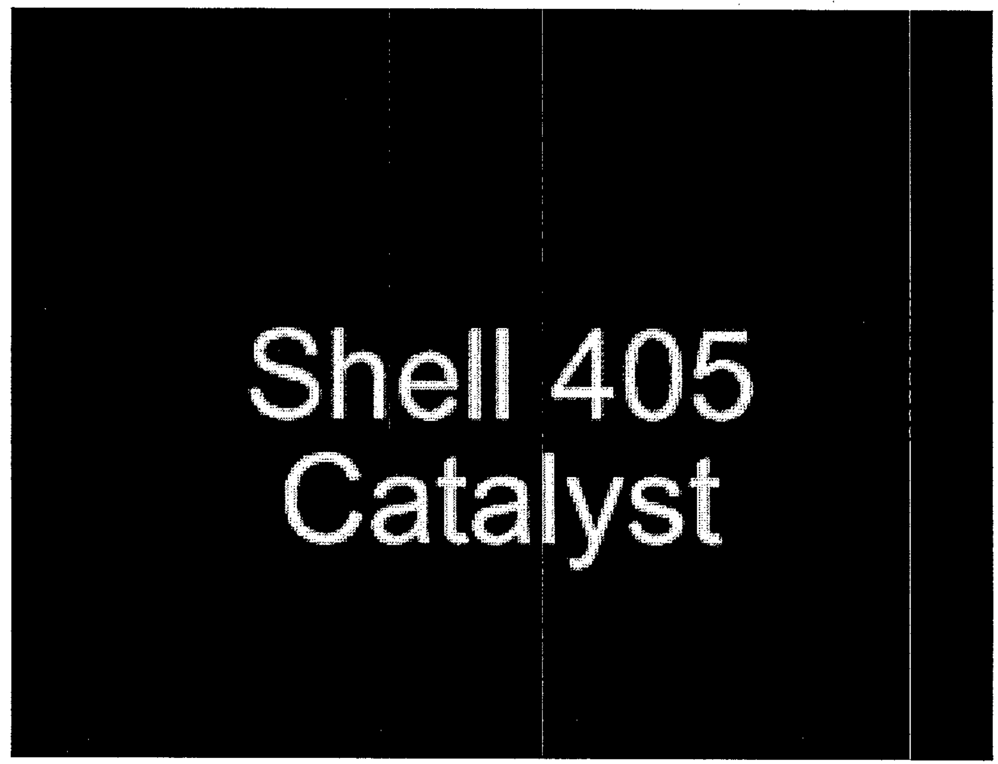


SPLASH PLATE TEST OF A PROPELLANT

Propellant Ignition Assessment

AFRL Pino Test

- **Pressure: 750 torr**
- **Catalyst Temp: 400 C**
- **Ignition Response Time < 20 msec**



APU Program Summary

- Monopropellant Formulation Study
  - Candidate assessment and selection completed
- Property Characterization
  - Propellant candidate production completed
  - Physical property tests completed
  - Safety/Hazard tests completed
  - Catalyst reactivity tests in progress

Conclusions

- USAF sees winning combination of green propulsion coupled with high performance
- Significant technical progress made in "green" solid propellants, liquid bipropellants and monopropellants
- Continued support for this type of research and development is expected